POLAR SCIENCE FOR PLANET EARTH

Response of the lower atmosphere to changes in the global atmospheric electric circuit associated with solar wind variability

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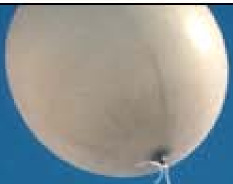

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TOSCA

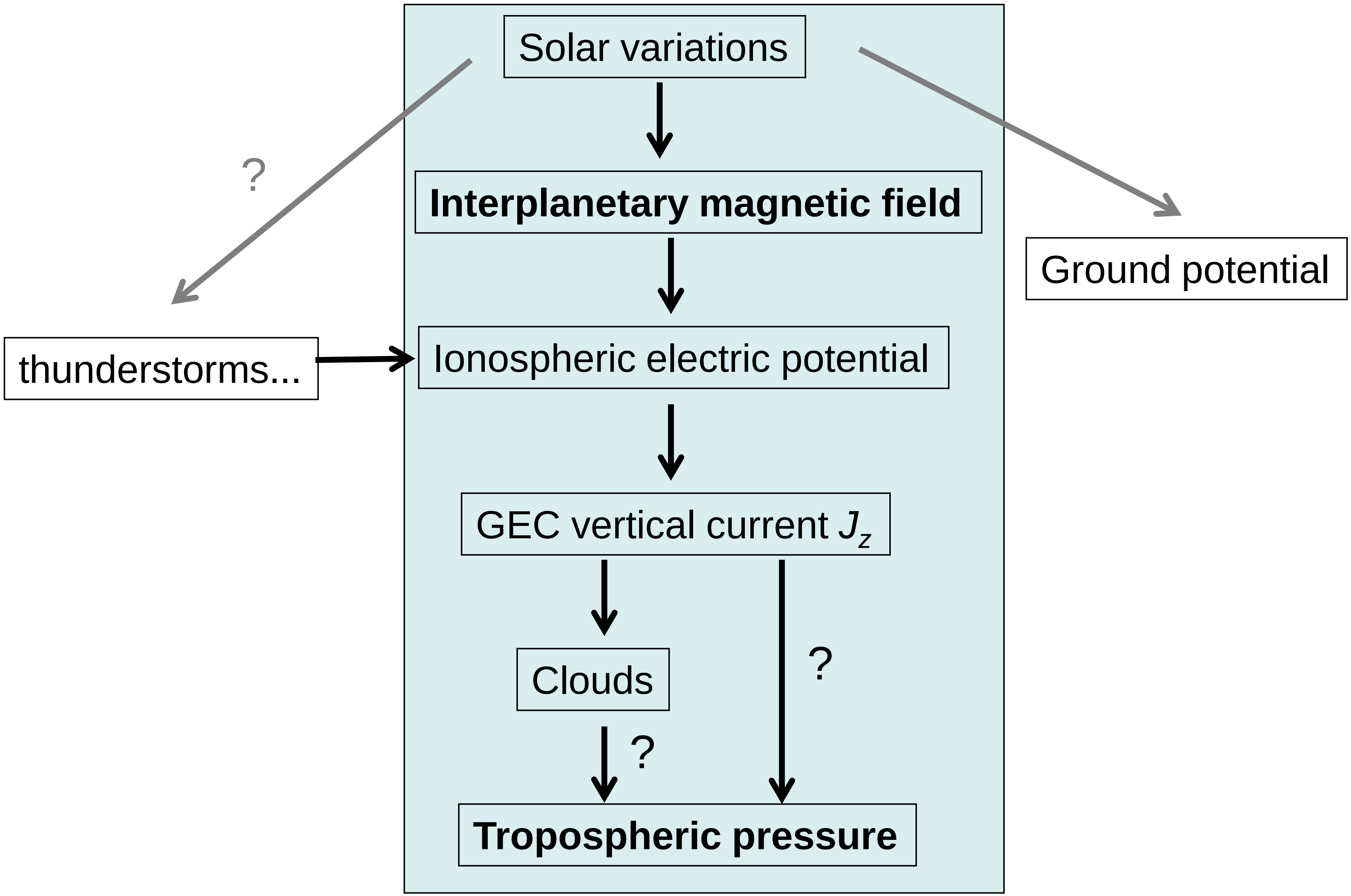
Outline

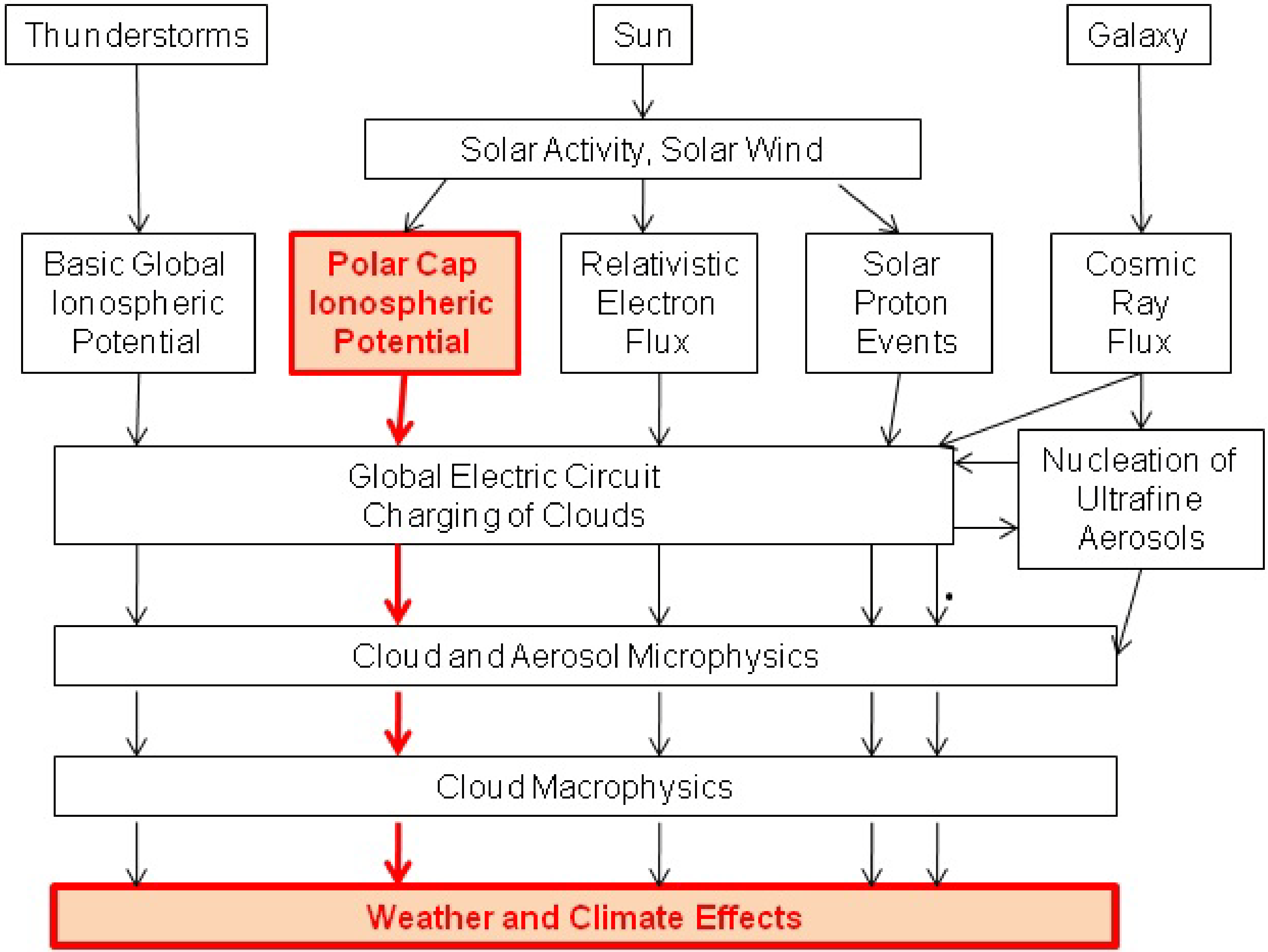
- Background and context
  - Mansurov effect: polar surface pressure variations & variations in B_y
  - Well-established, but little understood
  - Global atmospheric electric circuit?

- Results
  - Polar lower-atmosphere, time lag study
  - Global surface pressure study

- Conclusions

Chain of events: time scale day-to-day




Thunderstorms
Sun
Galaxy
Solar Activity, Solar Wind
Basic Global Ionospheric Potential
Polar Cap Ionospheric Potential
Relativistic Electron Flux
Solar Proton Events
Cosmic Ray Flux
Global Electric Circuit Charging of Clouds
Nucleation of Ultrafine Aerosols
Cloud and Aerosol Microphysics
Cloud Macrophysics
Weather and Climate Effects

What can change J_z ?

Changes in potential

- Global ionospheric electric potential
- Polar cap ionospheric electric potential

Changes in conductivity

- Relativistic electron flux changes
- Solar proton events
- Cosmic ray Forbush decreases

Solar Variability

What can change J_z ?

Changes in potential

- Global ionospheric electric potential
- Polar cap ionospheric electric potential

IMF B_y

Solar Variability

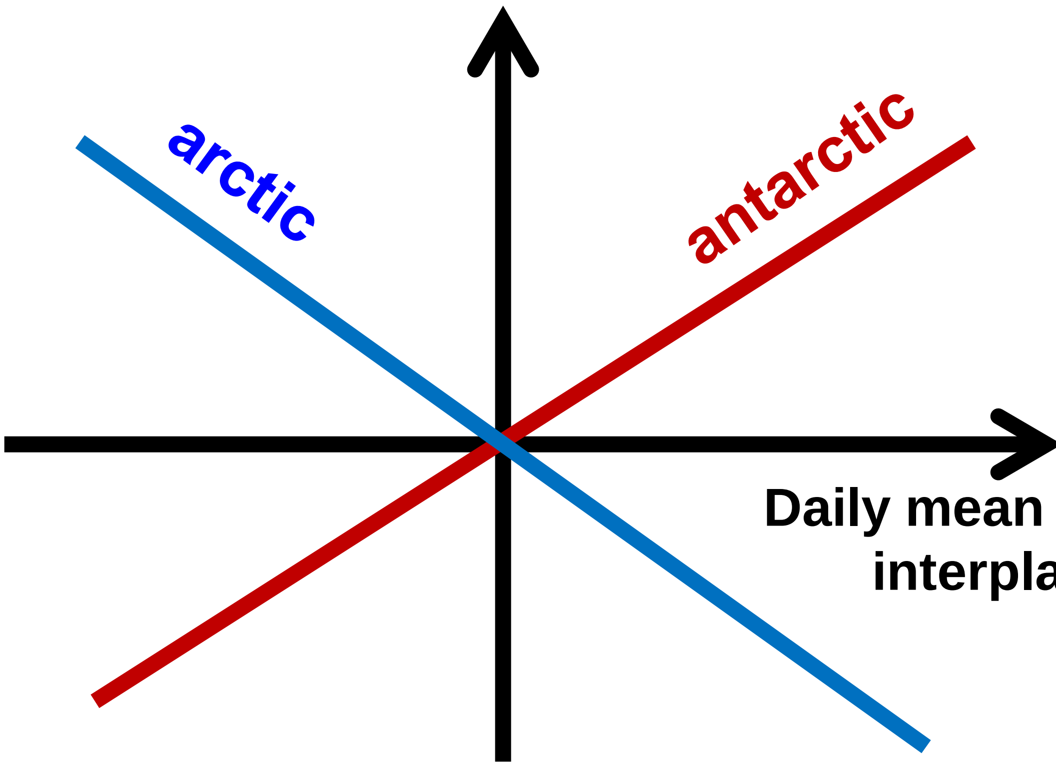
~~Changes in conductivity~~

- Relativistic electron flux changes
- Solar proton events
- Cosmic ray Forbush decreases

The Mansurov effect

- Polar
- Opposite sign N & S
- Persistence ~10 days
- Lag ~days
- Periodicity ~27 days
- Amplitude 1 - 2 hPa
- B_y

12 UT polar surface pressure anomaly



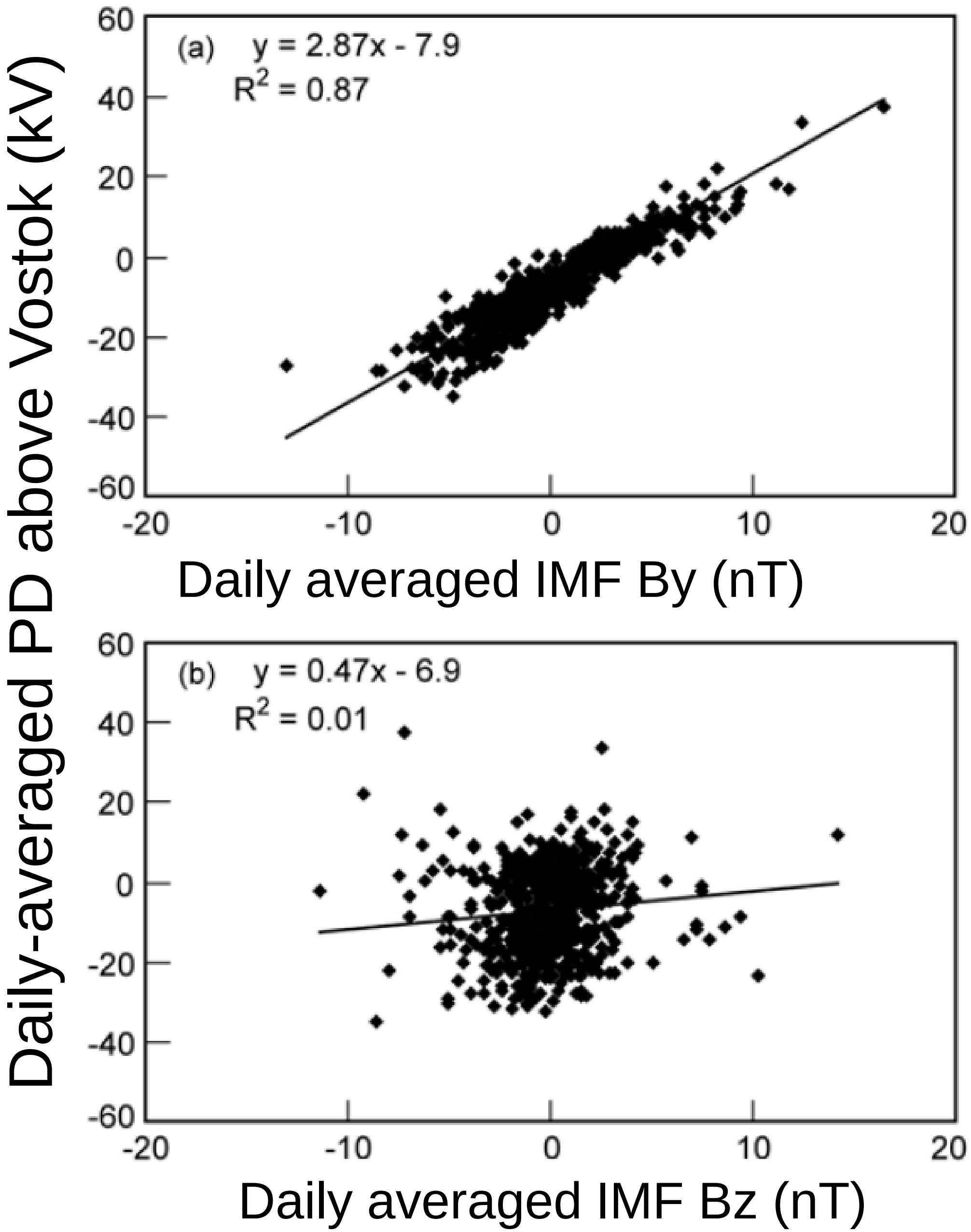
Daily mean dawn-dusk component of interplanetary magnetic field IMF B_y

Proxy for solar-wind-induced ***electric*** *potential in ionosphere* Φ_{sw}

Solar-wind-induced ionospheric electric potential (SWIP)

- Changes in product of B_y & solar wind velocity $v_x \Rightarrow$ changes in SWIP at high latitudes.
- Variations in SWIP associated with ionosphere-to-ground p.d. variations.

Polar solar-wind-induced ionospheric electric potential



- Strong cumulative influence of IMF B_y on SWIP. In contrast to B_z.
  Tinsley & Heelis [1993], Tinsley [2000]
- Empirical Weimer model (satellite, B_y, B_z, v)
- 87% of modelled SWIP controlled by B_y
- < 1% controlled by B_z
  Burns et al [2007]

Spatial change in ionospheric electric potential with change in IMF By

Large interplanetary magnetic field (IMF)

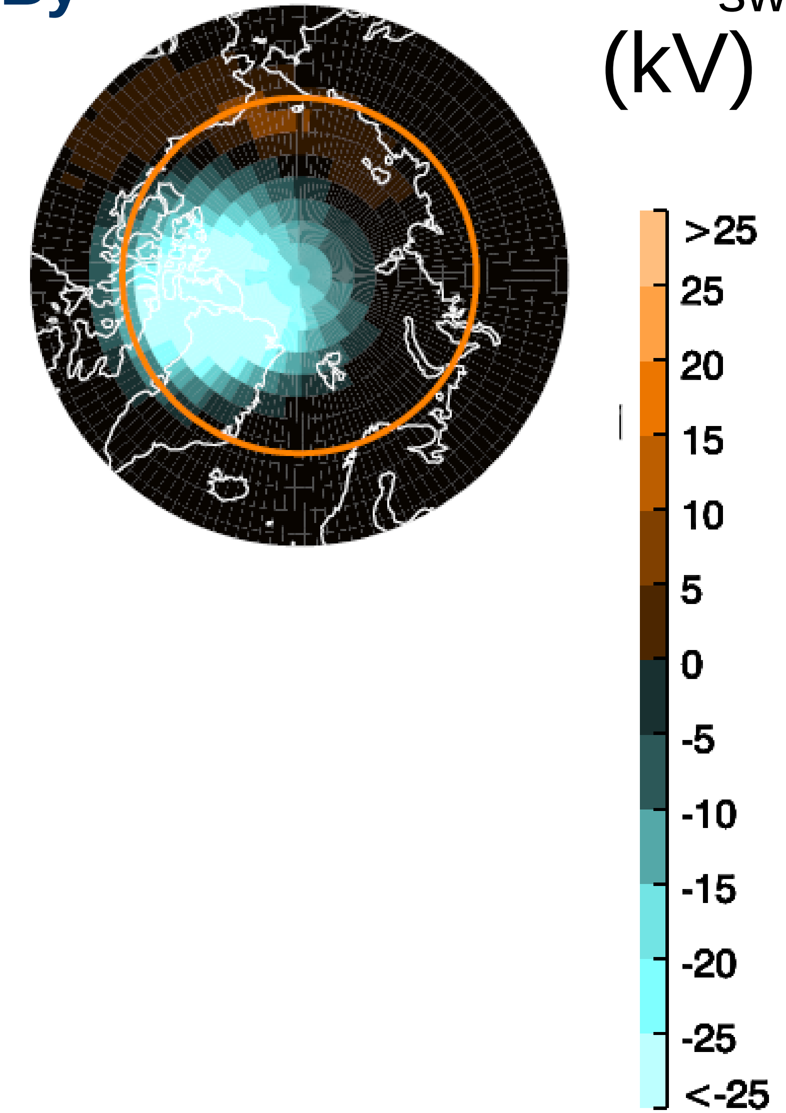
$5 < |\mathbf{B}| < 10$ *nT*

Change in IMF B_y
(large negative to
large positive)

Pettigrew et al. (2010)
1998 – 2002 SuperDARN radar database

Spatial change in ionospheric electric potential with change in IMF By

$\Delta\Phi_{SW}$ (kV)



Large interplanetary magnetic field (IMF)
*5 < |**B**| < 10 nT*

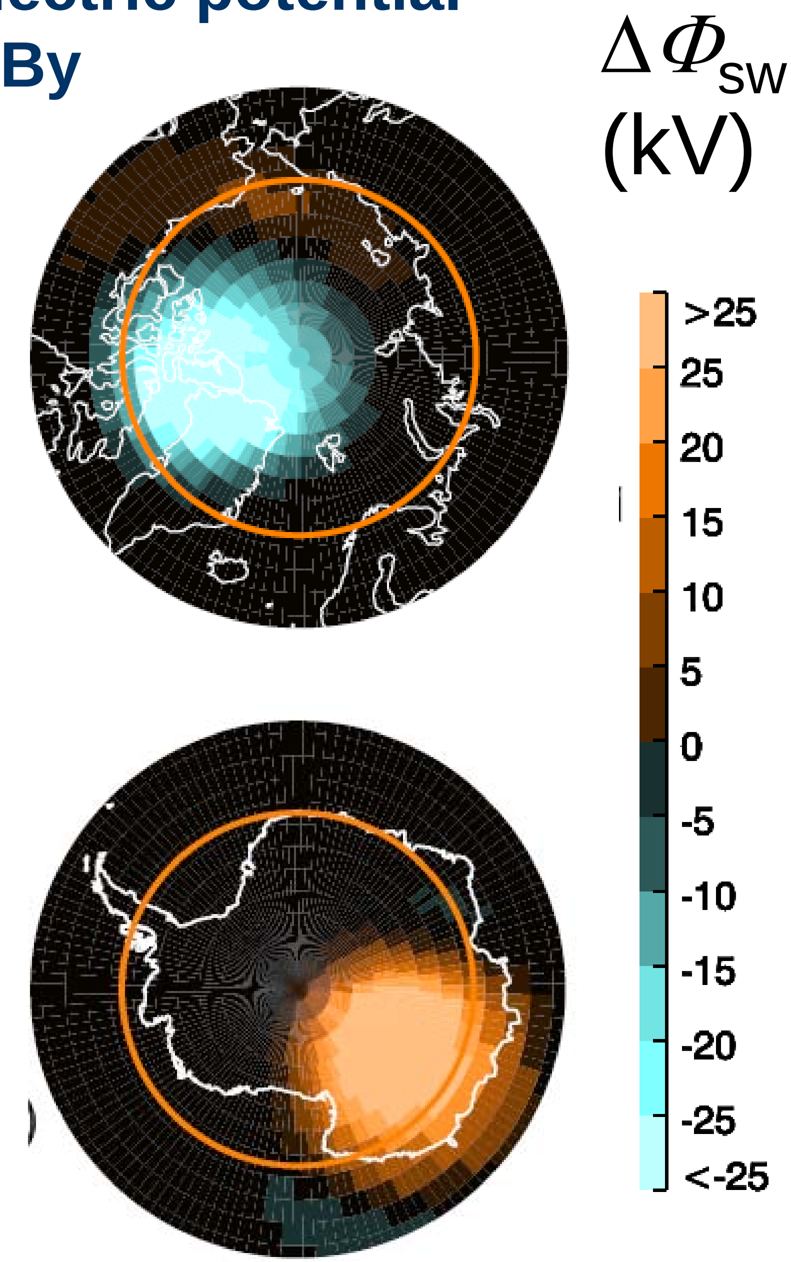
Change in IMF B_y (large negative to large positive) → Change in ionospheric potential (-ve N)

Pettigrew et al. (2010)
1998 – 2002 SuperDARN radar database

Spatial change in ionospheric electric potential with change in IMF By

Large interplanetary magnetic field (IMF)
*5 < |**B**| < 10 nT*

Change in IMF B_y (large negative to large positive) → Change in ionospheric potential (+ve S)



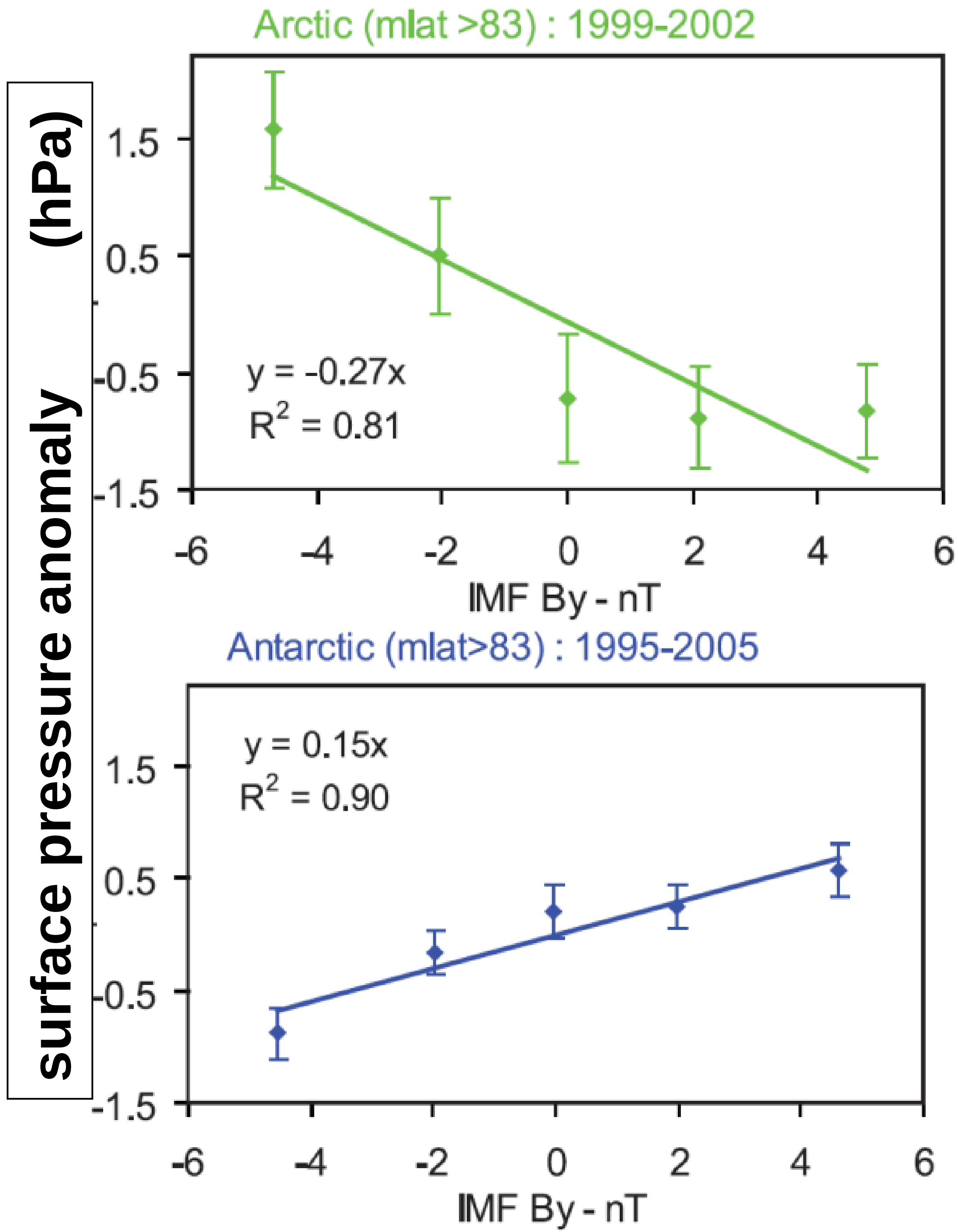
Pettigrew et al. (2010)
1998 – 2002 SuperDARN radar database

The Mansurov effect

Burns et al. 2008
Station data

11 Antarctic
7 Arctic

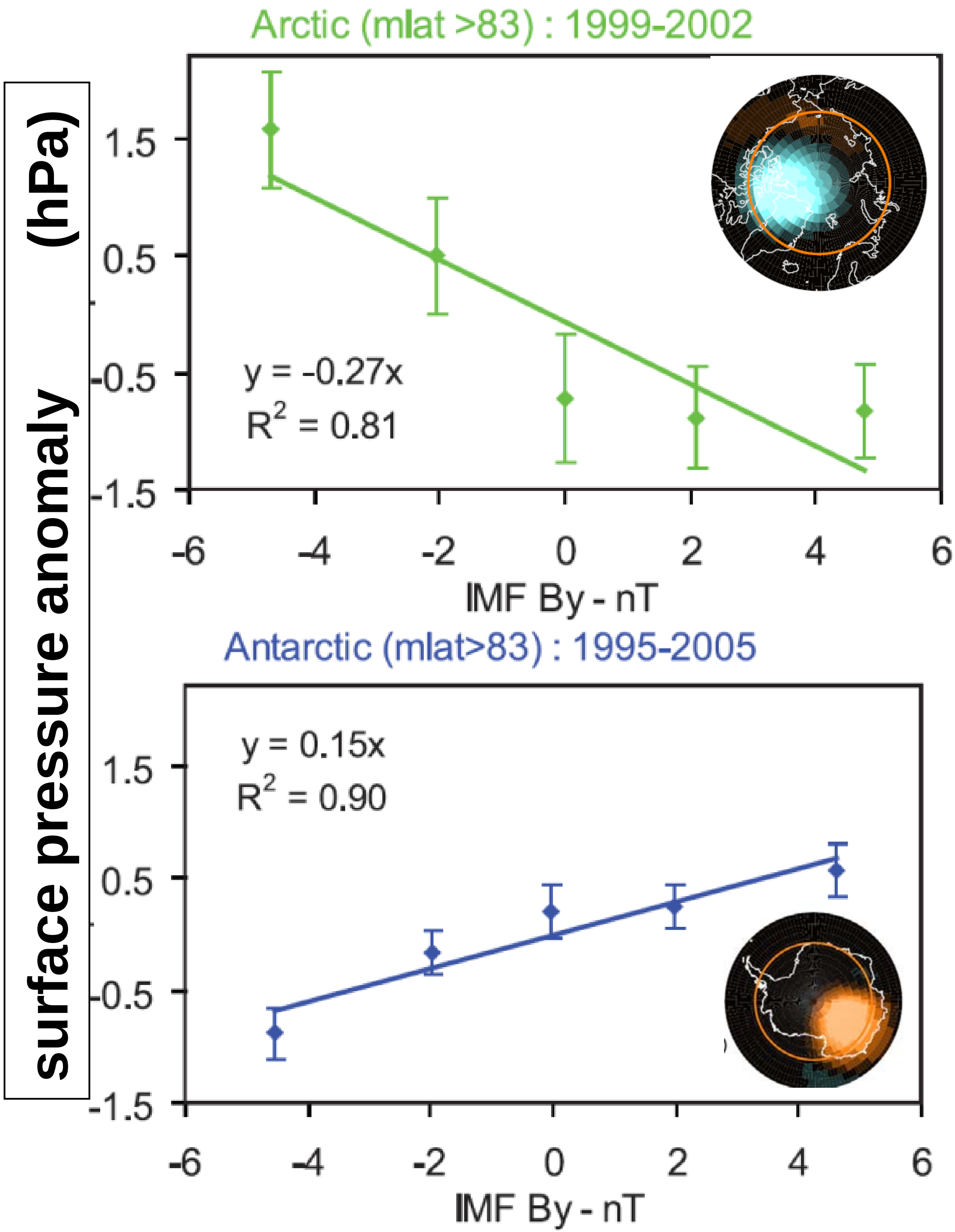
Verified by me with BAS archive.



The Mansurov effect

Change of Δp and Φ_{SW} with increasing IMF B_y **has same sign** within a given hemisphere

-ve in N
+ve in S

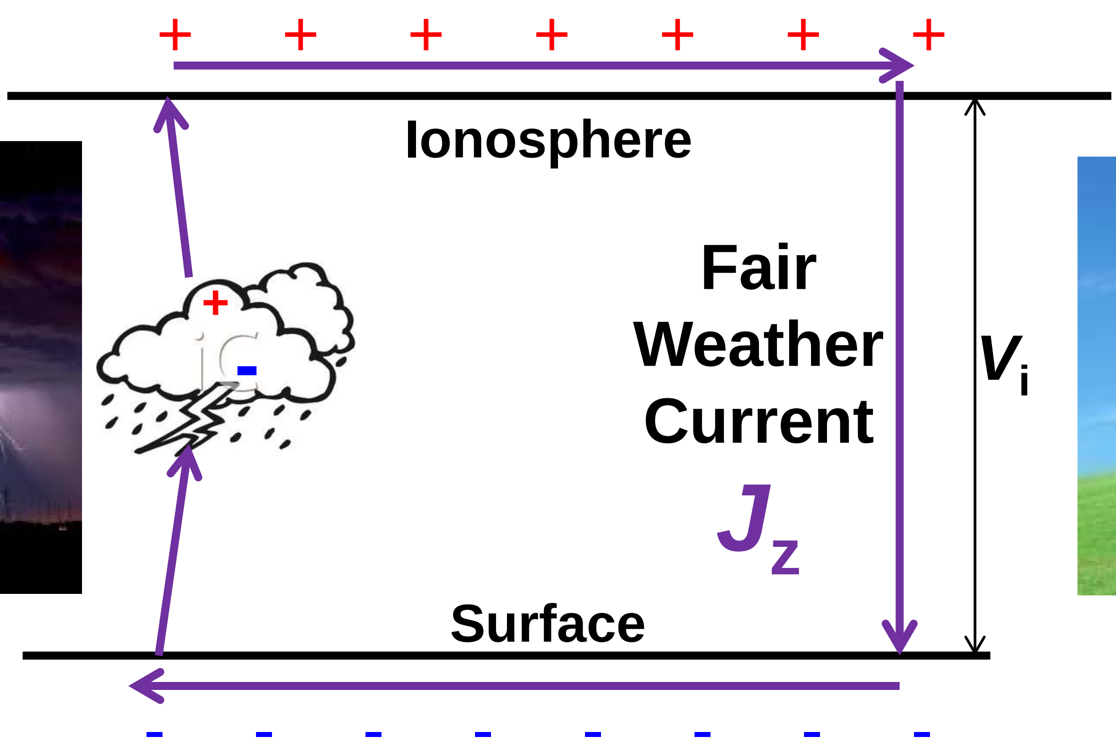


Global electric circuit in Earth's atmosphere

- Global thunderstorms: vertical electric potential difference V_T ~ 250 kV
- Additionally, solar-wind-driven component

$$V_i = V_T + V(\Phi_{SW})$$

- V_i drives horizontal currents along surface and ionosphere.
- Closed by ionosphere-ground global fair-weather currents J_z

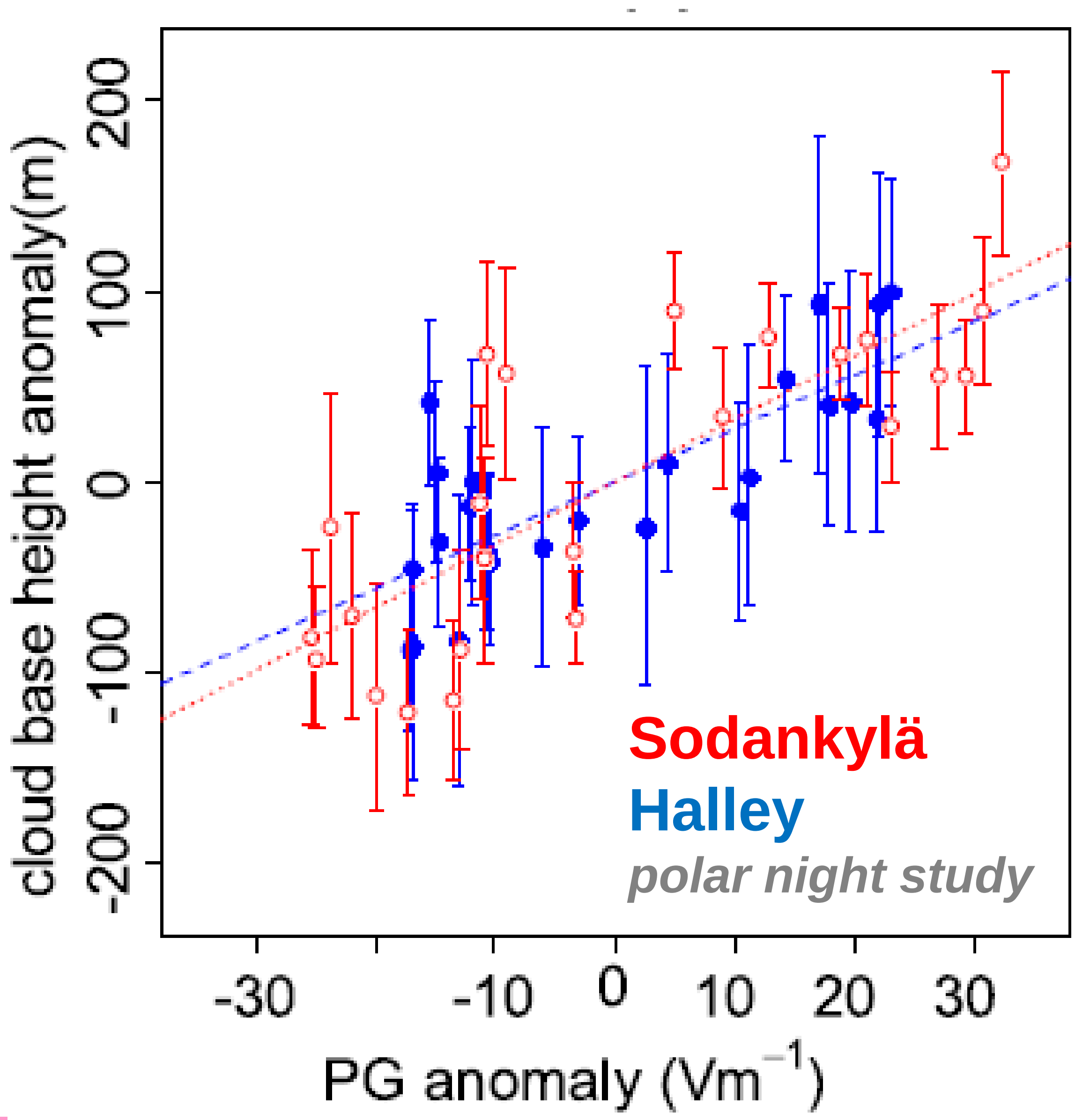


J_z can affect droplet growth rate at layer cloud base

Droplet formation height and updraught speed steady (on average)

⇒

averaged ceilometer cloud base height measures droplet growth variations

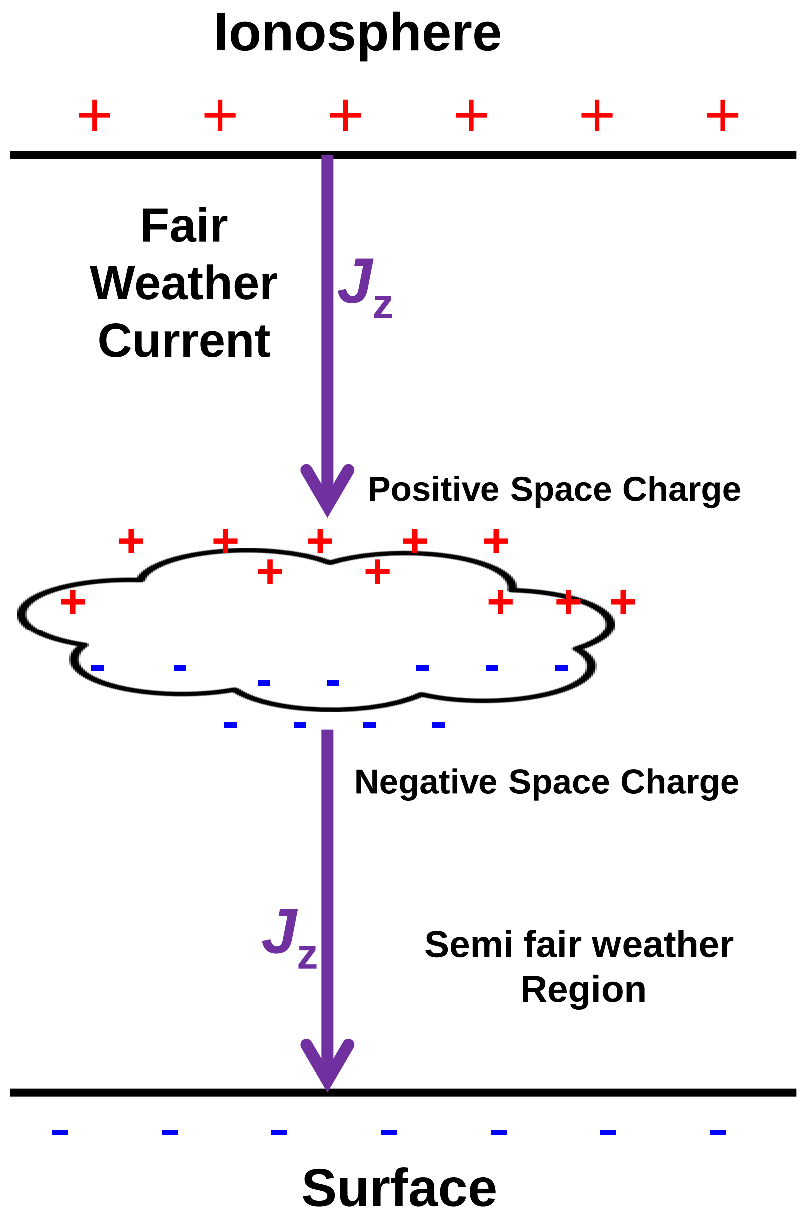


(potential gradient)

Harrison and Ambaum, 2013

Why might that indicate involvement of electricity?

- $J_z \Rightarrow$ electrification of cloud edges
- Condensation rate increased by charged condensation nuclei...
- ...vary with vertical current J_z
- Possible responses in scattering and emissivity, albedo



Three links between solar variability and atmosphere

1. **UV-ozone**
   Effect of solar UV variability on **stratospheric** O_3, hence radiation balance

2. **EPP-ozone**
   Effect of energetic particle precipitation (EPP) from space environment on **stratospheric** O_3, hence radiation balance

3. **Mansurov (GEC-cloud?)**
   Action of variations in global atmospheric electric circuit on cloud dynamics, hence radiation balance, heat budget...

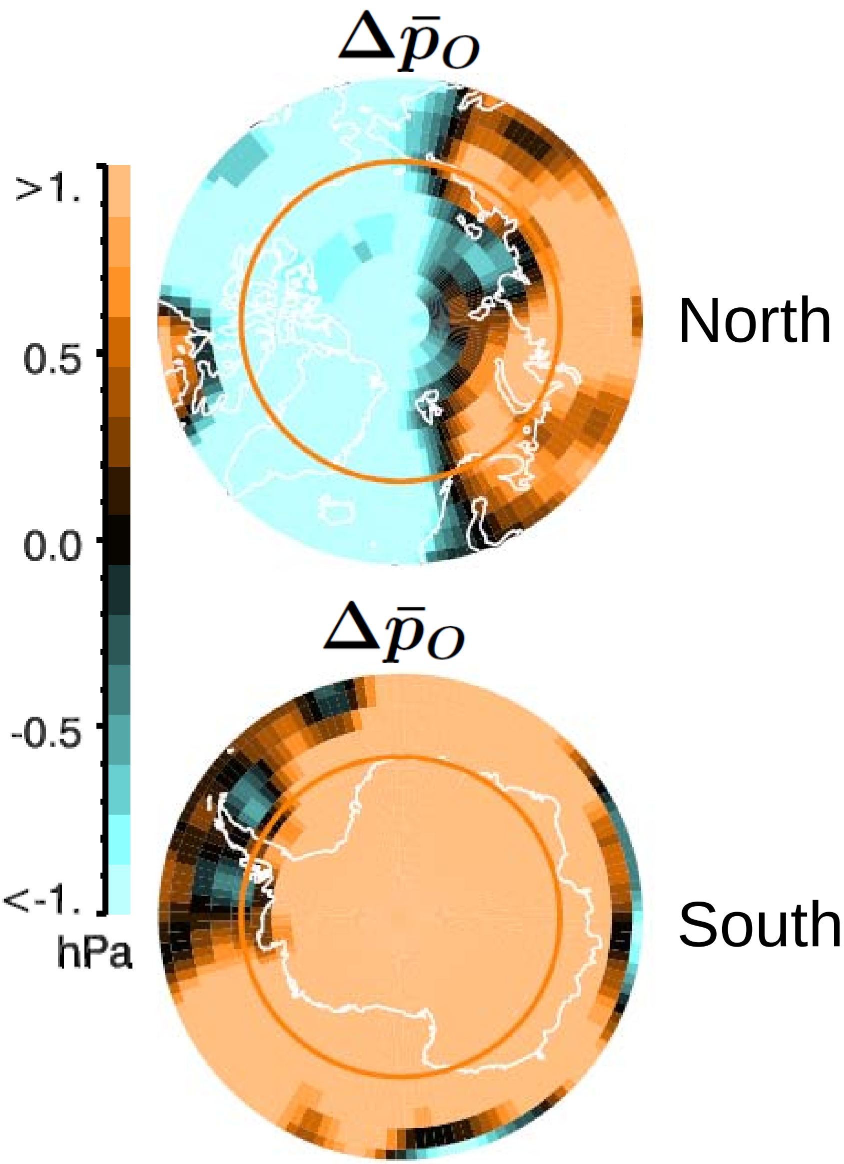
Spatial patterns

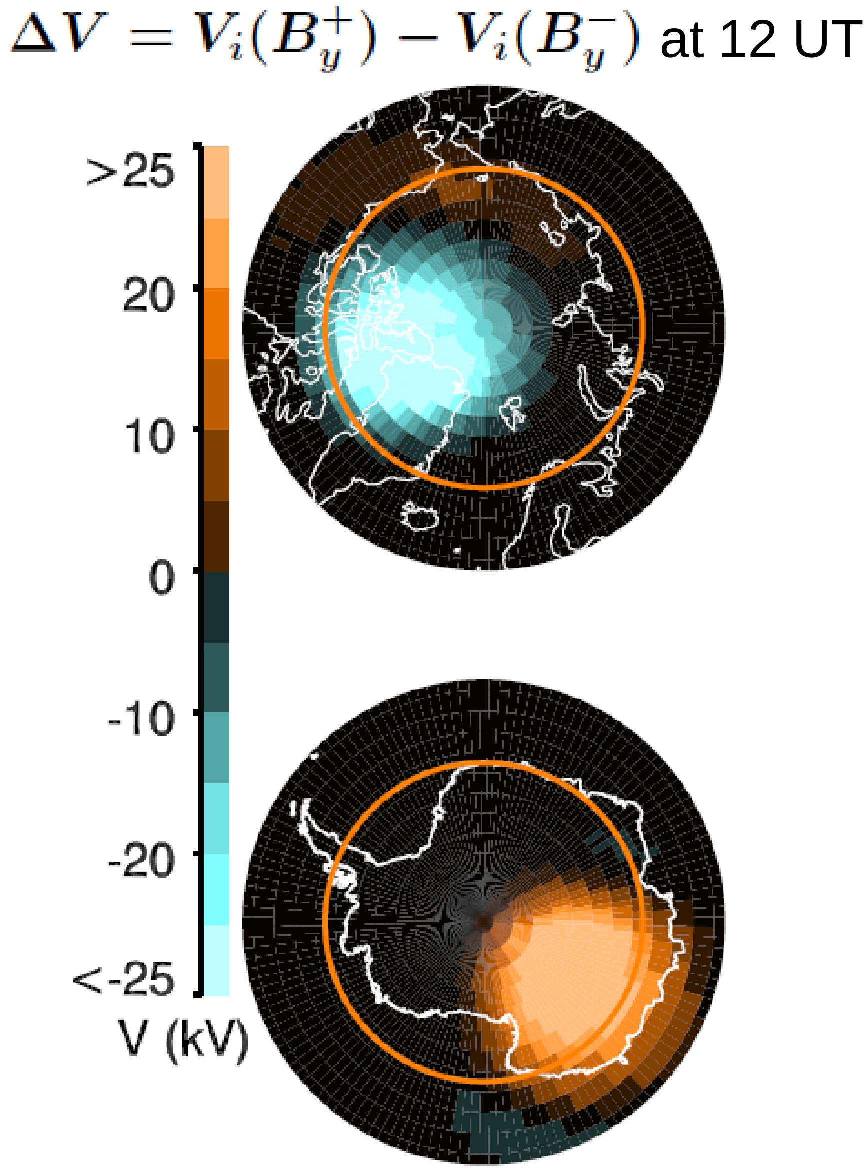
- Explore spatial distribution rather than spectral analysis

- Initial global, surface pressure, zero timelag study

$$\Delta \bar{p}_O(\boldsymbol{\lambda}, \phi) = \bar{p}_+(\boldsymbol{\lambda}, \phi) - \bar{p}_-(\boldsymbol{\lambda}, \phi)$$

Polar $\Delta\bar{p}_O$ resembles ΔV above 74 ° geomagnetic latitude



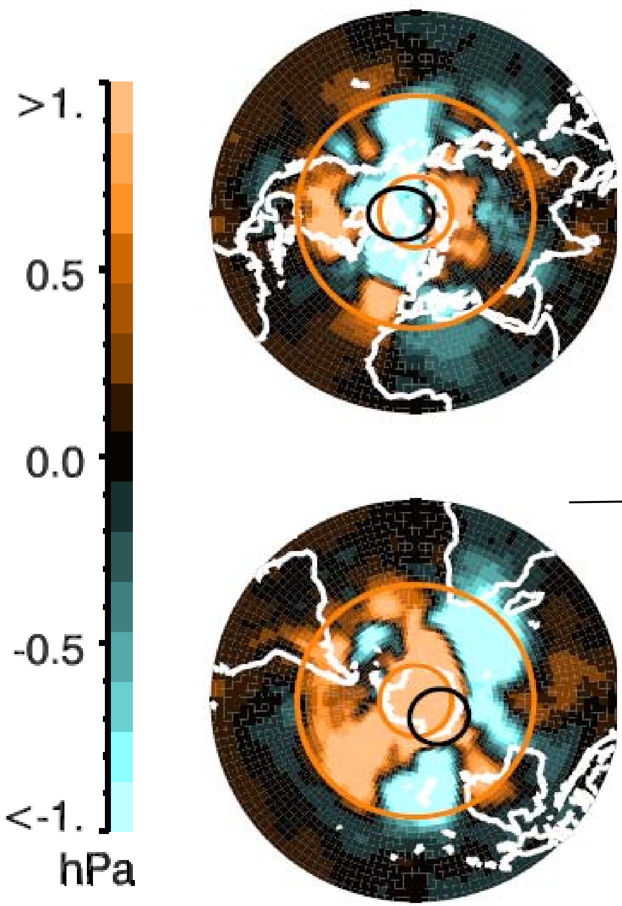


Orange circles at 70 °

Lam et al. 2013

2D pressure is ordered by IMF B_y at mid latitudes

$$\Delta\bar{p}_O(\lambda,\phi) = \bar{p}_+(\lambda,\phi) - \bar{p}_-(\lambda,\phi)$$



$\Delta\bar{p}_O(\lambda,\phi)$

Table 1. Field significances for WRS test between $\bar{p}_+$ and $\bar{p}_-$

Region	Latitude range (°)	Field significance (%, 2 s.f.)
Arctic	70.0 N–90.0 N	1.9
Mid latitude (north)	30.0 N–67.5 N	2.1
~~Equatorial~~	~~27.5 S–27.5 N~~	~~23~~
Mid latitude (south)	30.0 S–67.5 S	0.4
Antarctica	70.0 S–90.0 S	0.3
Globe	90.0 S–90.0 N	2.0

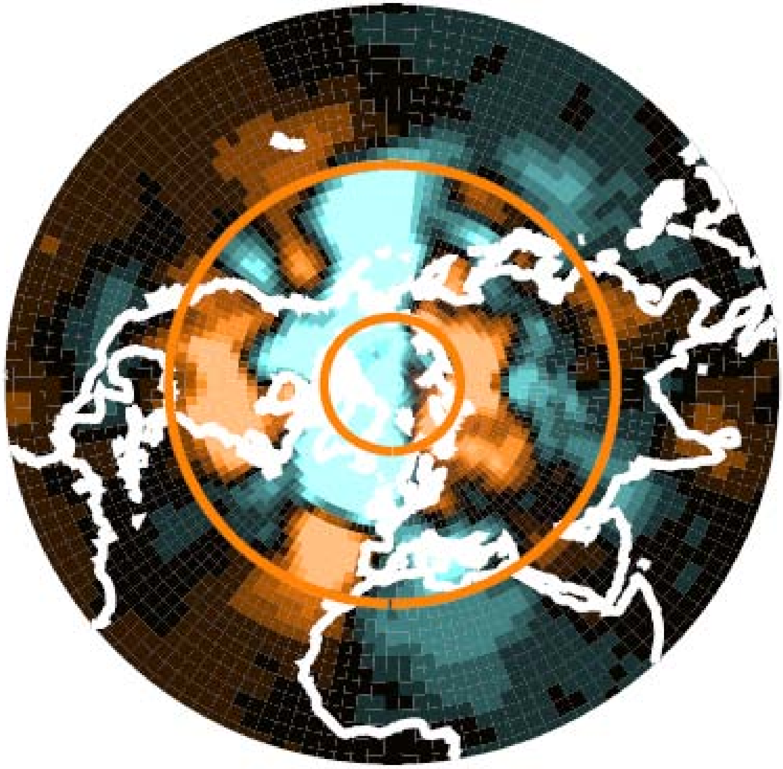
Orange circles at 30° and 70°

Lam et al. 2013

2D surface pressure ordered by IMF B_y in north resembles QS Rossby wavefield

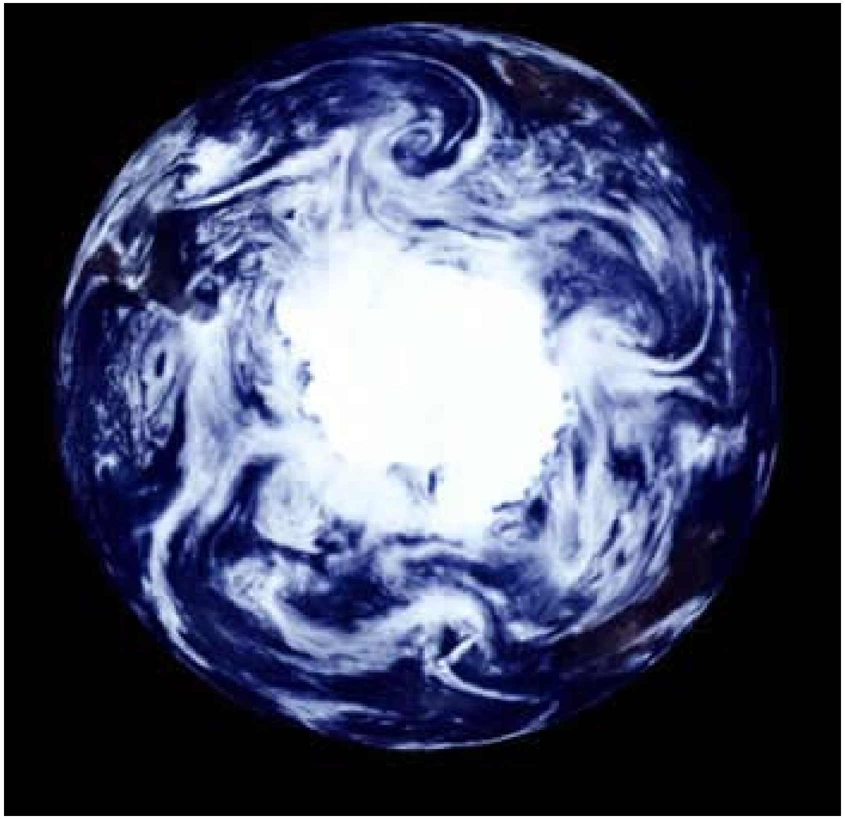
$$\Delta \bar{p}_O(\lambda, \phi)$$

North



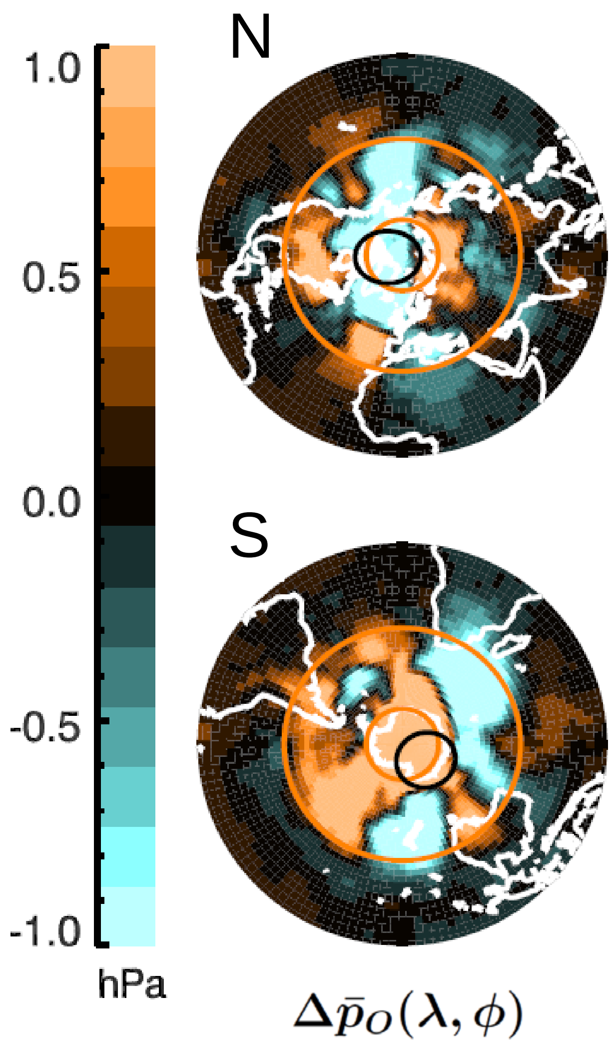
Orange circles at 30° and 70°

Quasi-stationary Rossby (planetary) waves

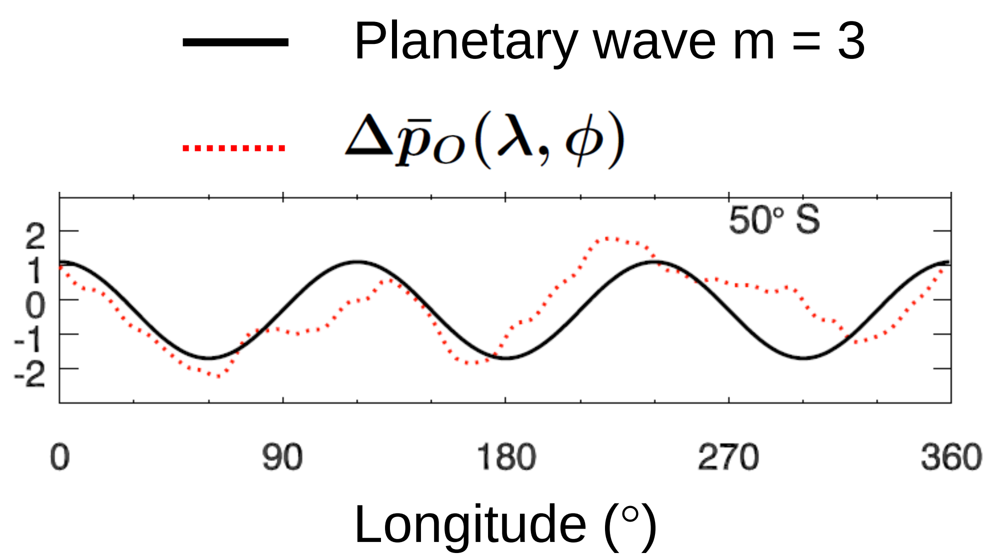


~ 4 – 6 waves at mid-latitudes (m = 4 - 6)

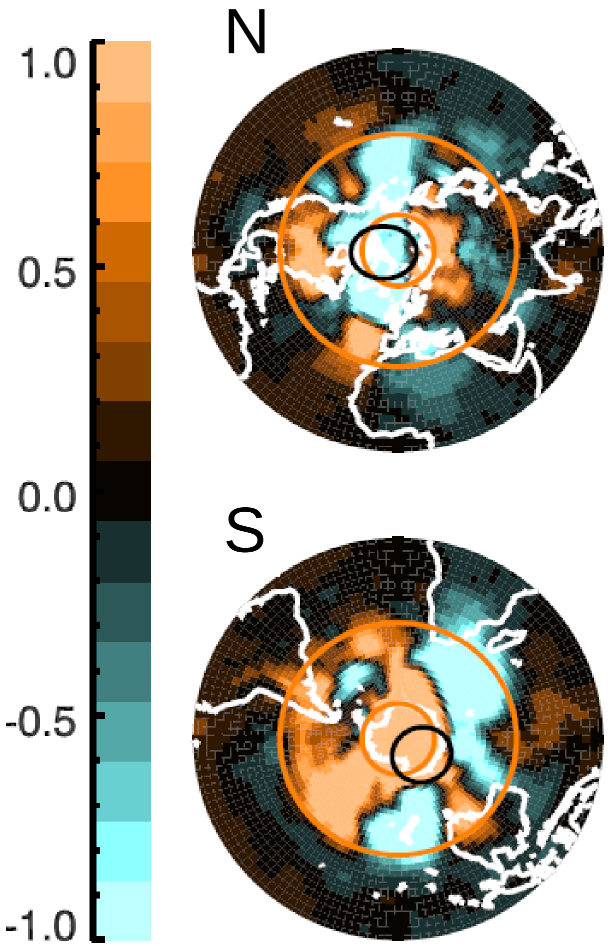
2D surface pressure ordered by IMF B_y in south resembles Rossby wavefield



- 2D variation in the southern hemisphere does not look as regular as in the north
- However, 50°S section shows m = 3 present



Mid-latitude Mansurov effect could be important



$\Delta\bar{p}_O(\lambda, \phi)$

- Size of $\Delta\bar{p}_O(\lambda, \phi)$ at mid latitudes similar to that in polar regions: ~ 1 - 2 hPa
- Corresponding zonal winds similar to initial uncertainties in ensemble numerical weather predictions of ~ 1 m/s

Lam et al. 2013

Change in latitudinal wavelength 2D QS Rossby waves

- Coriolis force varies linearly in co-latitude θ
- Stationary solutions for wind in longitudinal and latitudinal directions
- Integer number of azimuthal Rossby waves, *m*
- Geostrophic approximation – horizontal motion balanced by pressure force

Wavelength in latitudinal direction:

$$L_\theta = \frac{2\pi R \sin\theta}{[(4\omega^2 R^2 \rho \cos\theta \sin^3\theta)/(\mathrm{d}\bar{p}/\mathrm{d}\theta) - m^2]^{1/2}}$$

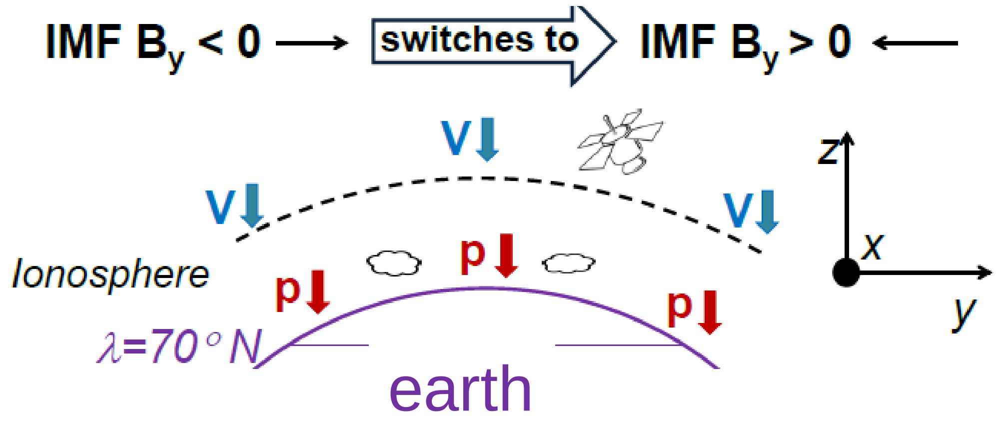
depends on meridional gradient of zonally-averaged pressure, which changes with IMF B_y

Accounts for Rossby-wave-like form of $\Delta\bar{p}_O(\lambda, \phi)$

Lam et al. 2013

2-stage mechanism

i. Change in polar pressure field involving global atmospheric electric circuit

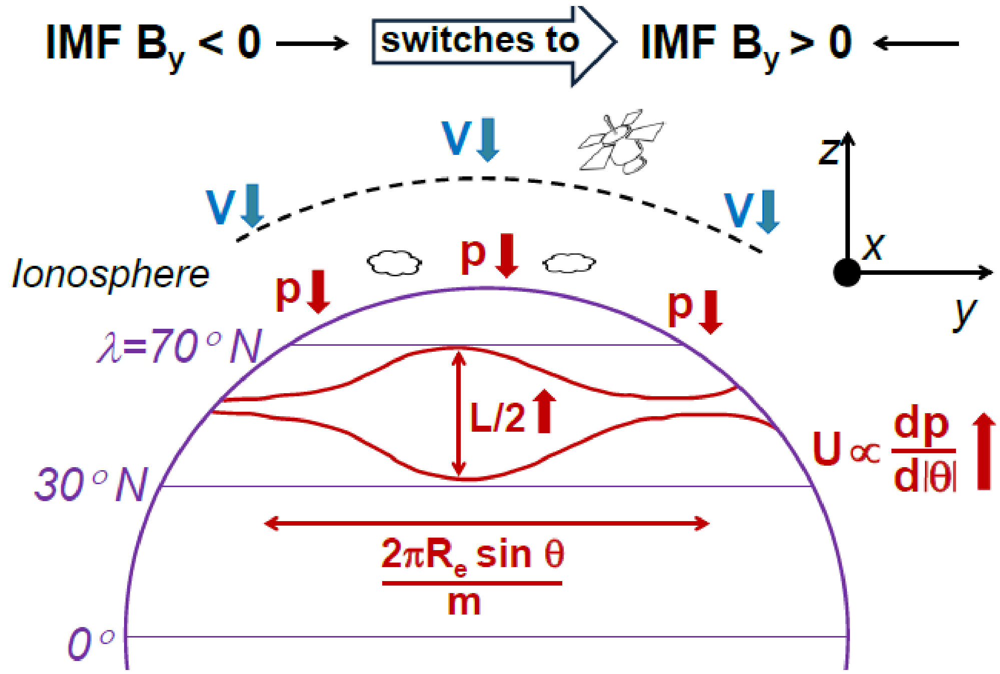


Lam et al. 2013

2-stage mechanism

i. Change in polar pressure field involving global atmospheric electric circuit

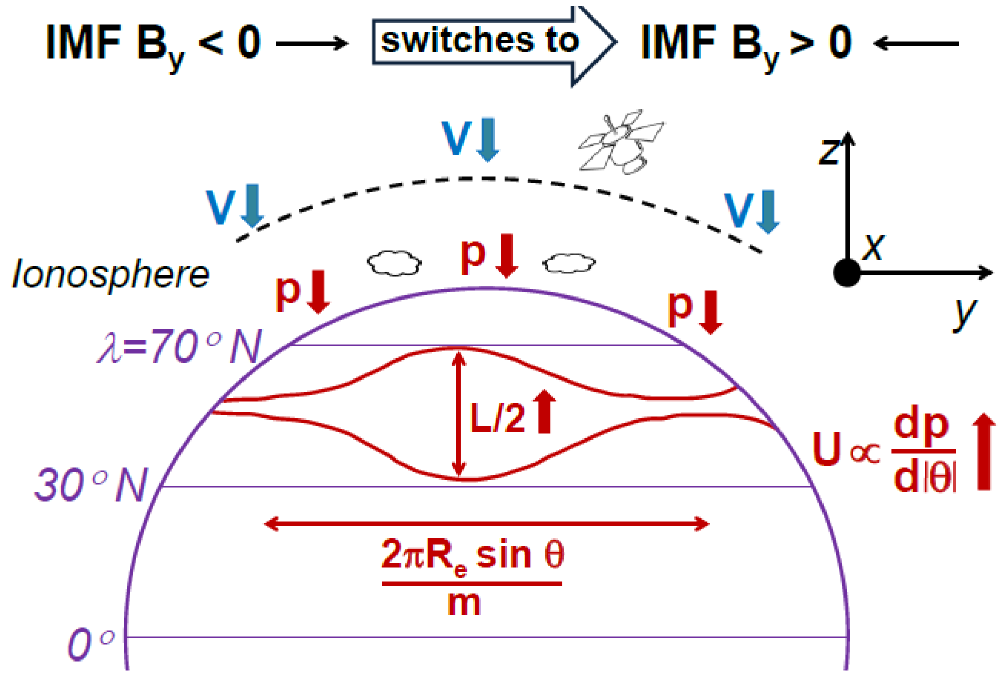
ii. Resulting change in L_θ via zonal wind change



co-latitude θ = 90° - λ

Lam et al. 2013

2-stage mechanism



- In varying between the two IMF By states, we vary between two similar planetary wave patterns.

co-latitude $\theta = 90° - \lambda$

Lam et al. 2013

Implications

- Rossby wave field key in determining trajectories of storm tracks

- Configuration of North Atlantic jet stream particularly susceptible to changes in forcing...

- ... as are location/timing of blocking events? ($\Rightarrow$ periods low/high pressure)

Importance of small effects
(nonlinear dynamics)

Summary

- Changes in IMF B_y correlate to significant changes in pressure:

  - in troposphere and base stratosphere (Antarctic)
  - on timescale of days
  - peak in correlation occurs with higher timelag at high altitudes

- Globally, strongest and simplest behaviour in Antarctic

- Difference in mean surface pressure for high positive and negative IMF B_y:

  - polar mean resembles ionospheric electric potential
  - mid-latitude mean resembles planetary wave field

- 2-stage mechanism (i) polar, (ii) mid-latitude:
  (i) direct action of ionospheric potential on cloud dynamics via GEC
  (ii) associated changes to atmospheric pressure modify planetary wave field via zonal wind

- *NCEP Reanalysis data provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from http://www.esrl.noaa.gov/psd/*
- *OMNI data obtained from GSFC/SPDF OMNIWeb interface http://omniweb.gsfc.nasa.gov*
- *SuperDARN model of ionospheric potential created by Ellen Pettigrew*